

Summary Abstract: Scanning electron microscopy with polarization analysis: Studies of magnetic microstructures

R. J. Celotta, J. Unguris, and D. T. Pierce
National Bureau of Standards, Gaithersburg, Maryland 20899

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Surface magnetism is an emerging discipline with many challenging scientific and technological problems. Consequently, traditional methods used to measure the magnetization of materials need to be extended to include ultrathin films and microscopic magnetic structures. Scanning electron microscopy with polarization analysis¹⁻³ (SEMPA), which promises to have a significant impact on these measurement problems, was suggested by a measurement⁴ of the spin polarization of low-energy secondary electrons emitted from a magnetized Fe-based glass. The secondary electron polarization was found to reflect both the magnitude and direction of the sample magnetization. This led us to consider⁵ using a finely focused incident electron beam, such as found in a scanning electron microscope, to stimulate the secondary electron production which would permit the measurement of a target's magnetization in a region defined laterally by the incident beam dimensions and in depth by the mean free path for the escaping electron cascade.

The instrument developed for this purpose consisted of an UHV scanning electron microscope which was modified by the addition of electron optics to collect the secondary electrons from the target and transport them to a spin polarization detector system. Since the polarization information conveyed by the secondary electrons reflects the surface region magnetization, an UHV system is required. A positive consequence of the surface sensitivity is that thin magnetic films can be studied with no loss in sensitivity. The polarization detectors used are of a new, compact design⁶ developed for this purpose. Standard surface preparation and analysis techniques are included in the SEMPA instrument.

The spatial resolution obtainable in SEMPA will depend on the ultimate resolution of the scanning electron microscope, the current available at that resolution, the scan time, and the magnetization of the sample. A resolution of 100 Å should be obtainable. Polarization detectors lie between secondary electron detectors and Auger energy ana-

lyzers in efficiency, so typical magnetic images are intermediate between secondary and Auger images in the time required for accumulation. An important feature of SEMPA is that the same electrons that are measured to give the magnetization image also produce the secondary image. Hence, the physical structure and the magnetic structure of the surface are measured simultaneously but independently. It is therefore possible to directly correlate the effect physical structure has on magnetic structure.

We have studied a variety of samples using the SEMPA technique. Domains have been imaged in an Fe-3% Si single crystal showing striking irregular domain patterns, including the so-called "fir-tree" pattern. Examples of physical defects, visible in the secondary image, can be seen determining the location of domain walls in the magnetization image. Co-Ni films have been studied to ascertain the shape of the domain walls with the objective of probing the limitations put on magnetic recording density by domain structure. Ferromagnetic metallic glasses were imaged and displayed a stress-dependent, complex domain structure. The magnetization within the ~500-nm-wide domain wall of one such sample was imaged showing it to have a Néel character, i.e., in-plane spin rotation, rather than the Bloch or out-of-plane spin rotation usually associated with thick samples. Finally, thin-film Permalloy was imaged in the form of a magnetic recording head. Here, the vector character of the SEMPA measurement allowed the observation of closure domains at the periphery of the device and detected a defect in the physical structure near the writing surface.

Although a relatively new technique, SEMPA is rapidly finding application to a wide variety of magnetics problems and is being adopted in an increasing number of laboratories. This is expected to be particularly true of laboratories involved in magnetic storage and devices because SEMPA affords the means to study magnetic systems on the scale necessary to meet the demand for higher density recording

systems. Because of its surface sensitivity, SEMPA should prove very useful in gaining an understanding of the novel monolayer magnetic systems now being proposed. By virtue of the high spatial resolution available in SEMPA, studies of spin rotation within domain walls and of dimensional effects in structures with sizes comparable to domain wall widths will be possible. We expect to see SEMPA playing an important role in the study of micromagnetism in the future.

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